EAST Search History

Ref #	Hits	Search Query	DBs	Default Operator	Plurals	Time Stamp	
L1	18	(estimating or calculating) with (cost or fee or charge) with manufacture with (material or component)	US-PGPUB; USPAT	OR	ON	2007/08/17 14:50	a4
L2	23	(estimating or calculating) with (cost or fee or charge) with manufacture and (secure or password or log$in)	US-PGPUB; USPAT; JPO	OR	ON	2007/08/17 14:50	a4
L3	34	(estimating or calculating) with (cost or fee or charge) same manufacture and (secure or password or log$in)	US-PGPUB; USPAT; JPO	OR	ON	2007/08/17 14:50	all
L4	99	("4744028" | "4847761" | "4887207" | "4887218" | "4905144" | "4931944" | "5058026" | "5063506" | "5109337" | "5140526").PN. OR ("5249120").URPN.	US-PGPUB; USPAT; USOCR	OR	ON	2007/08/17 14:50	
L5	30	L4 and (secure or password or log$in)	US-PGPUB; USPAT; USOCR	OR	ON	2007/08/17 14:50	all
L6	1241473	secure or password or log$in	US-PGPUB; USPAT; USOCR	OR	ON	2007/08/17 14:50	
L7	204643	(update or change or sent) with (database or memory)	US-PGPUB; USPAT; USOCR	OR	ON	2007/08/17 14:50	
L8	5718	L7 same L6	US-PGPUB; USPAT; USOCR	OR	ON	2007/08/17 14:50	
L9	1240	L8 and "705".clas.	US-PGPUB; USPAT; USOCR	OR	ON	2007/08/17 14:50	
L10	212	L9 and manufacture	US-PGPUB; USPAT; USOCR	OR	ON	2007/08/17 14:50	all abs
L11	411	(choose or pick or select) with (value or price or cost) with component with (plurality or multiple)	US-PGPUB; USPAT; USOCR	OR	ON	2007/08/17 14:51	
L12	23	L11 and "705".clas.	US-PGPUB; USPAT; USOCR	OR	ON	2007/08/17 14:51	all
L13	68377	(plurality or multiple) with (provider or sender or manufacture)	US-PGPUB; USPAT; USOCR	OR	ON	2007/08/17 14:51	

EAST Search History

L14	142573	(choose or pick or select) with (value or price or cost)	US-PGPUB; USPAT; USOCR	OR	ON	2007/08/17 14:51	
L15	266	L14 same L13	US-PGPUB; USPAT; USOCR	OR	ON	2007/08/17 14:51	
L16	79	L15 and "705".clas.	US-PGPUB; USPAT; USOCR	OR	ON	2007/08/17 14:51	a 11
L17	1241473	secure or password or log$in	US-PGPUB; USPAT; USOCR	OR	ON	2007/08/17 14:51	
L18	204643	(update or change or sent) with (database or memory)	US-PGPUB; USPAT; USOCR	OR	ON	2007/08/17 14:51	
L19	5718	L18 same L17	US-PGPUB; USPAT; USOCR	OR	ON	2007/08/17 14:51	
L20	1240	L19 and "705".clas.	US-PGPUB; USPAT; USOCR	OR	ON	2007/08/17 14:51	
L21	391	L20 and (deny or reject or refuse)	US-PGPUB; USPAT; USOCR	OR	ON	2007/08/17 14:51	a 11 abs

POWERED BY **Dialog** LOGOFF

Search results: **2** titles

select all none Titles on this page: Display Checked Display All

---

Search Report

Database Name	**Database Number**
ABI/INFORM	15
PROMT (90-PRESENT)	16
TRADE&INDUSTRY	148
PROMT (1972-1989)	160
COMPUTER DATABASE	275
Set	**Description**
S1	(((estimating OR calculating)(1N)(cost OR fee OR charge)) AND (manufacture(1w)(material OR component)))
S2	PY=((1970:2000))
S3	S1 and S2
S4	S3
S5	RD
S6	SORT /ALL/pd,a

☐ **1** Cutting assembly costs with molded parts. - July 21 - 1988 - Gale Group Trade and Industry Database™

☐ **2** A parametric contract modeler for DFM analysis - 1996 - Word Count: 6004 - ABI/INFORM®

---

select all none Titles on this page: Display Checked Display All

To display full records, click a title or use the checkboxes and display buttons

POWERED BY Dialog

Cutting assembly costs with molded parts.
Dewhurst, Peter
Machine Design , Volume: 60 , Number: 17 , Page: 68(5) , July 21 1988

Cutting Assembly Costs with Molded Parts Engineers have become increasingly aware that manufacturing cost of a new product is essentially fixed in the earliest design phases. Once product design is set, it is too late to make the types of radical changes that could bring about major reductions in manufacturing costs. Unfortunately, reliable cost estimates, which could affect design decisions, are seldom available until component details have been decided upon and processing plans prepared.

This is one reason Design-for-Assembly (DFA) methods are being used to bring about manufacturing-cost reductions. DFA forces designers to look at the product designs as a whole and to search for a design that lends itself to efficient assembly. This approach seeks to minimize the number of parts in the product, and the benefits of this in terms of total manufacturing cost reduction and reliability improvements are well established.

However, in the manufacture of component parts, DFA leads designers in a direction opposed to traditional principles of producibility. Producibility guidelines were developed on the premise that it is always best to design parts such that the simplest individual processing methods are used. Rules like "design sheet-metal parts with two parallel edges," "keep bendlines in one plane," and "avoid cross-features in molded parts" all guide the user to design simple parts that have low individual tooling and processing costs. However, taken together at the product level, these parts often represent an inelegant design that has high assembly costs and poor reliability.

DFA is only one part of a Design-for-Manufacture (DFM) methodology that takes maximum advantage of material and process capabilities. In DFM, materials and manufacturing processes are carefully selected at the earliest design stage. Usually, DFM methods result in complex individual parts that contain the largest possible number of required features. The resulting assembly design thus has minimum rather than maximum part count, low total manufacturing cost, low assembly costs and high reliability. Benefits associated with such a design include simpler production control, reduced inventory, and easier implementation of just-in-time procedures.

Injection molding is a process that lends itself well to DFM methodology through its ability to produce complex geometric shapes in a single operation. Perhaps the most widely recognized, innovative, injection-molded prouct using DFM methods is the IBM Proprinter.

IBM developed the Proprinter to compete with Japanese dot-matrix printers. Complex plastic components in the Proprinter design incorporated the functions of cantilever springs, bearings, support brackets and fasteners into single snap-fit components. Integrating several features into single, complex parts resulted in a final assembly of only 32 parts with an assembly time of approximately 3 minutes. This can be compared with the Epson MX-80 printer that had been previously sold with IBM PC's, which has 152 parts, requiring over 30 min of assembly time.

However, to fully implement DFM, whether using injection molding or any other process, the design team needs to obtain early cost information, both to make sound comparisons between material and process alternatives and to quantify the effects of design decisions on total manufacturing cost. A

recently developed microcomputer program for estimating cost of injection-molded components has been developed with these objectives in mind.

The program, Parts Cost Estimating -- Injection Molding, from Boothroyd Dewhurst Inc., allows engineers to enter information about the type of mold, the part size, part features, part quality, and the material to be used. To simplify the process, the program conains a complexity calculator, which determines the geometric complexity of the mold from information about the part design. Part volume and area calculator worksheets are also accessible from the main program screen. The program, which runs on IBM microcomputers and compatibles, gives both the total cost of manufacturing the part and a breakdown of mold, processing, and material costs.

Machine database

When a part is analyzed by the program, the number of cavities that should be used in the mold is estimated first. A mathematical procedure identifies the optimum cavity count using the cost of one cavity and matching cores, the required production volume, and the molding cycle time. The program then automatically selects an appropriate machine from the machine database, part of which is shown in Table 1. The machine is chosen to have sufficient clamp force and shot size for the given number of cavities, as well as a maximum clamp opening sufficient to separate the part from cavities and cores. Other data in the machine database is used by the program to calculate hourly rate, resetting time, and fill time.

The relative operating cost given in the third column of Table 1 is used, together with a basic rate (in $/h) for a 500-kN (approximately 50 ton) machine, to establish the appropriate hourly cost rate for the chosen machine. This rate is adjusted if the machine is operating semiautomatically, with a three-plate mold, for example, or fully automatically, as with a hot-runner or hot-manifold system.

The dry cycle time is used to estimate the time required to open and close the clamp unit through the distance necessary to eject the part being analyzed. This time, together with the time required for actual ejection of the part, constitutes the machine resetting time. However, empirical data suggest that actual operating times are 1.5 to 2 times longer than the dry cycle times uses in the database, partially because relatively slow clamp opening time is required to ensure distortion-free stripping of molded parts from the mold cores. Reset time in real cases is also affected by the difference in acceleration and deceleration times during partial clamp movements, and this is allowed for in the program.

The data is the last tow columns of Table 1 are used to approximate the fill time for a single or multi-cavity mold. The driving-power value is the average power available from the injection unit, assuming the full shot size can be injected at maximum speed. This value can be converted to a maximum flow rate for any given pressure. The value in the last column of the machine database represents maximum flow rate for a pressure of 1,200 bars.

In calculating cavity fill times, the program uses a proportion of the available machine driving power, depending on the average wall thickness of the part being analyzed. For thin parts, high-speed filling may cause polymer chains to orient with preference to one direction, and part distortion may occur. Thus, only a small proportion of full power is used to fill thin parts, whereas for thick-wall parts almost full-power filling is assumed possible.

Material database

A section of the material database is shown in Table 2. The data for each polymer includes items to calculate mateiral cost for a given part volume (columns 1 and 2) and additional information needed to estimate machine size and the cooling portion of cycle time. The recommended injection or nozzle

tempertaure (column 3), recommended mold temperature (column 4) , and thermal diffusivity coefficient (column 6) are required to generate the cooling curve. Column 5 contains the typical cooling time for a 2.5-mm-thick wall of the chosen polymer. This value is used to align the cooling curve, given by heat conduction solutions, to the single data point.

The name of the part to be analyzed is entered on the upper row of the main computer response screen, represented by Table 3, and a material such as polypropylene is selected from the database. The upper left-hand window of the response screen is then completed. The part volume is entered first, to establish the amount of polymer to be used per part. This value defines the appropriate machine shot size for single or multicavity operation, and is used to estimate the likely fill time.

Part volume is determined by using a volume calculator that is incorporated with the program. Pressing the V key while in the main response screen transfers operation to a worksheet, where a range of solid and hollow volume elements can be selected from a graphics menu to build up the required part geometry.

A similar calculator is available to estimate the projected part area. This is the second piece of data that must be entered in the upper-left window of the response screen. It is needed to estimate the required clamp force per cavity. The recommended injection pressure from the material database is also used in making clamp force estimates, together with typical pressure losses in the sprue, runner, and cavity channels.

The total amount of pressure losses is contained in a central database that the user can review before an analysis. This database also contains such factors as base-machine hourly rates; basic costs, which can be used to interpolate the cost of an appropriately sized mold base; and other machine-shop performance and production parameters as well.

In Table 3, L, W, and D are the dimensions of a rectangular box that surrounds the part and is aligned with the molding directions. These dimensions are used to identify the appropriate plate area and combined thickness of the mold base. They also are used to establish the required clamp stroke for part ejection.

Two wall thickness values also are requested. The maximum thickness is used to estimate the cooling portion of cycle time. The average value is used to establish the appropriate filling rate. Also, volume is divided by the average thickness to obtain an approximate value for the part surface area, which is one parameter used in estimating the cost of the required cavity and core.

The remaining values are used to establish the cost of the required single or multicavity production mold. The mold-costing algorithms used in the program were developed after discussions with different moldmakers. The procedure used is based on the assignment of points for various part attributes, with the points normalized to correspond to mold manufacturing hours.

A basic point score is first given for the manufacture of one cavity and matching core, based on part size. This basic score includes the average cost of both a gating and an ejection system, which are again governed solely by part size. Additional point scores are assigned according to the geometric complexity of the inner and outer surface of the part, the typical level of tolerances applied to the part dimensions, and the required appearance value of the part.

Each part attribute is given a rating between 0 and 5. Descriptions of the different rating levels are given on help screens which can be obtained for every response. For example, appearance level 0 applies to opaque parts with noncritical appearance, while appearance level 5 is for transparent parts of optical quality.

In assigning point scores to the mold, the tolerance, appearance, and complexity factors are not independent. For example, points assigned for a given appearance level are determined according to both part size and geometric complexity. To assist in determining the appropriate geometric complexity level, another calculator is used. Using this calculator, the main geometric features are counted, as well as the number and type of surface patches covering the part. The data are weighed to produce the required geometric complexity rating

Using the software

The purpose of this software is to allow product design teams to make early cost estimates for injection-molded parts and to test the cost effects of individual design changes. For example, a heater core cover currently being produced by a U.S. auto manufacturer is made using a six-cavity mold. The program estimated a cost of $36,383 for this mold. The mold cost breakdown is shown in Table 4. The actual cost of the mold is $38,750.

A total production volume of 1 million parts was assumed, because the actual value was not known. In analyzing this part, the number of cavities was changed from the optimum number of eight, given by the program, to six, corresponding with the actual mold being used.

Analysis results, shown in table 5, include mold, manufacturing, and polymer costs per part, which together added up to total part cost. Total mold-base costs and cavity/core manufacturing costs combined to give the total mold cost. Total mold cost was divided by the number of parts produced to give the mold cost per part. Manufacturing costs per part were determined by the machine size, rate, and cycle time. Part weight and volume were used to determine the polymer cost per part.

For the present mold design, estimated cycle time was 42.8 s, corresponding to a 40-s cycle time reported by the manufacturer. The long cycle time was caused by the four thickened pads used to increase stiffness around the four small holes in the flange.

The abrupt increase in wall thickness at the pads violated rules of good design for injection-molded parts. This produced localized sink marks on the undersurface of the pads in the actual part. However, the appearance of the part was not critical, because it was not visible when installed, and the present design has the advantage of being associated with low cavity and core costs.

An alternative to the present design would be to both thicken and core out the clamping pads, producing equivalent stiffness through ribbed structures. This design change would achieve a uniform part wall thickness with a consequent cycle-time reduction -- but at the expense of a major increase in cavity complexity.

However, when computer analysis of the redesigned mold was compared to analysis of the existing design, it became clear that reduced cycle time would lead to fewer cavities being required. As seen in Table 6, a two-cavity mold for the revised design would result in a higher production rate than that obtained with the present six-cavity mold. Thus, although the cost of a single cavity and core would increase by 45%, the total cost of the required production mold would decrease by an estimated 36%. This cost reduction, combined with the reduced cycle time and the use of a smaller molding machine could produce an estimated 33% reduction in part cost.

Captions: Cycle times for ABS components. (graph); Molding and heater core cover design data. (table); Heater core cover design. (chart)

Copyright © 1988 Penton Publishing Inc.

Gale Group Trade and Industry Database™
© 2007 The Gale Group. All rights reserved.
Dialog® File Number 148 Accession Number 3672162

POWERED BY Dialog

Dialog eLink: USPTO Full Text Retrieval Options

A parametric contract modeler for DFM analysis

Philpott, M L Warrington, C S Branstad, E A David, R Nita, R P

Journal of Manufacturing Systems , v15n4 , Page: 256-267 , 1996 (includes Charts Graphs Equations References)

A parametric contract modeler is presented for providing manufacturing cost information to engineering designers during the early conceptual design phase of new product development. Access to manufacturing cost information is particularly important during the early nonlinear and cyclic development of a design. It is during this time that the overall product structure is cast and where a large percentage of the cost is effectively committed. A factorial design approach is described for identifying key cost drivers of a process and for developing practical cost models from contract quotes. These empirical cost models may then be used to make rapid ball-park cost estimates on both recurring and nonrecurring manufacturing costs during the initial design phases, as an integral part of the iterative design-for-manufacturing process. Two methods of converting cost data into usable cost information are presented: comparative cost charts and integrated CAD interface.

Headnote:

Abstract

Headnote:

A parametric contract modeler is presented for providing manufacturing cost information to engineering designers during the early conceptual design phase of new product development. Access to manufacturing cost information is particularly important during the early nonlinear and cyclic development of a design. It is during this time that the overall product structure is cast and where a large percentage of the cost is effectively committed. A factorial design approach is described for identifying key cost drivers of a process and for developing practical cost models from contract quotes. These empirical cost models may then be used to make rapid ball-park cost estimates of both recurring and nonrecurring manufacturing costs during the initial design phases, as an integral part of the iterative design-for-manufacture process. Two methods of converting cost data into usable cost information are presented: comparative cost charts and an integrated CAD interface. In the former, cost data are graphed, which is particularly useful for rapid visual cost comparison of manufacturing processes and part features. In the latter, the cost model is embedded in a parametric feature-based CAD solid modeling system, and cost estimates are presented on the computer screen as the design is created.

Keywords: Cost Estimating, Cost Models, Factorial Design, Features, Design for Manufacture (DFM)

Introduction

Design for manufacture (DFM) has evolved over the past decade or so from a general awareness of the need to consider more thoroughly the ease and economics of manufacture into a set of structured

strategies, methodologies, and tools for evaluating a design for its manufacturability.

Spiraling costs and the emergence of global competition have put an emphasis on design-to-cost strategies, where cost is elevated to the same level of concern as performance and function, from the moment the new product is conceived.' Design-tocost strategies require cost estimates at each stage in the product development process. However, the average engineering designer knows little about the cost of materials and processes implied and specified through the design drawings. Manufacturing options even for simple parts are numerous, and the effects on both recurring costs (piece-part costs) and nonrecurring costs (tooling costs) are dramatic.

Rapid cost estimating systems are necessary to enable product designers and product development teams to make sound decisions early in the conceptual design phase and not, as is often the case, provide fodder for later value-analysis teams.2 The conscientious design engineer is interested in the existence of any design tradeoffs that can be made to help converge on the most economical approach.

Many product manufacturers outsource much of their primary manufacturing. In some cases, they will only carry out the final assembly process or even just final distribution and marketing. The product designer in such an environment is concerned with designing the highest quality product for the lowest cost manufacture by local, national, or offshore contractors. Access and understanding of cost even at the conceptual design stage of the product development process is key to the realization of competitive world-class products.

This paper presents a parametric contract modeler for providing absolute and comparative manufacturing cost information to engineering designers and product development teams at the early iterative stages of product development. A factorial design methodology is presented for identifying key cost drivers of a process and for developing empirical cost models directly from contract quotes. Research results show how the methodology has been applied to the injection molding process. Finally, two user interfaces are described for accessing and using the cost data during the iterative product design process.

Background and Review

Early formal cost estimation techniques used nomography.34 Nomographs are still used and allow several product parameters to be incorporated into a cost estimate. Computer-based cost estimation packages became available in the early 1960s.' These computer packages typically computerize the process of breaking down a component into detailed process plans. The user must have detailed knowledge of the process and be able to formulate both the plan and the associated costs. These costs are typically based on "standard times" derived from time and motion studies.

Cost estimating is an integral function of most companies and is typically carried out by one of the following methods:8

Process plans/Routing sheets:9,10 The detailed step-by-step breakdown of the complete production process by experienced process planners or cost estimators, typically using standard times and deriving costs from standard rates.

Comparative historical data analysis: The estimator derives estimates from knowledge of previous products and their resulting costs. Costs are adjusted to suit variation in parameters such as part size, complexity, material, processing requirements, and so on.

Conference method:10 Estimates are based on discussion between experienced representatives from various departments or between estimators with various materials and processing expertise.

Contract quoting: Detailed design packages are sent to specialist contractors for quotes.

Mechanistic process models:11 Detailed production times and costs are calculated based on mathematical models of the manufacturing process.

Parametric cost estimation:12 In parametric cost estimating, key parameters of the part and the process are identified as the main cost drivers and only these key parameters are used for the cost analysis.

The cost estimating activity in a company has traditionally occurred when the product development process is almost complete. The activity is carried out by cost estimators or cost engineers who have little or no role in the design or development process. Their main responsibility is to supply accountants with cost data for profit analysis and/or sales pricing.

More recently, contemporary companies have formally extended the role of the cost estimator to provide direct support to product development teams for comparison of alternative designs during product development and for competition analysis and new product viability studies. This has been difficult for a number of reasons, and several issues have proved hard to resolve. In particular, current estimating procedures overburden the cost engineer and/or the designer and overextend the product development cycle time. Also, the different backgrounds and technical cultures of the cost estimator and designer have made constructive cooperation difficult.

Understanding the relationship between product design parameters, key process parameters, and process cost has been the focus of work by several researchers. This work has tended to be process-specific and has typically focused on the development of mechanistic process models based on key process parameters, for example work by Poli on injection molding" and die casting.14

Perhaps the most comprehensive research work currently being done in this general area is collaborative work being carried out by researchers at Rensselaer Polytechnic Institute and the University of Massachusetts at Amherst under the NSF Strategic Manufacturing Initiative project, "A Unified Representation to Support Evaluation of Designs for Manufacturability.15-17 The goal of the research is "...to investigate features as a unifying concept for a representation that supports the evaluation of designs or components and assemblies for functionality, manufacturability, and tolerance accumulation, at both the configuration (early in the process) and parametric (detailed) stages of design." The development of cost models is not the primary focus of the research but is included in the work. The researcher are taking a feature-based mechanistic process modeling approach to model development. The work focuses on feature-based representations at multiple levels of abstraction, with "features" as the integrator or enabler.

A number of computerized parametric cost estimating packages have emerged over the past few years utilizing a combination of mechanistic models, time and motion study based standard times, and company-specific user inputs such as depreciation rate and burden.ls-zo For example, for a turned component the cost estimating package might typically break down the total unit cost into material cost, setup cost, machining cost, and part handling cost utilizing a relationship such as:

Process planners or traditional cost estimators are accustomed to planning each job in great detail, as this is a necessary part of the production process. The design engineer, on the other hand, will typically have little knowledge of much of the data required as inputs to these current models and cost estimating software packages. The design engineer will usually not know the capability of a potential contractor's machines, or their machine rates, operator labor rates, or appropriate overhead rates. For designers, who are primarily exploring design alternatives, this level of detail is not only beyond their training but also too time consuming. Also, the feedback is slow and cumbersome and detracts from the creative design process. Comparative information is difficult to derive and assess, and absolute part costs are of

questionable accuracy, particularly where manufacturing is to be contracted out to an unknown entity (unknown at this stage, that is). When tools, process settings, standard times, and burden allowances differ so greatly from the actual ones used by the contractor, the cumulative error in the estimate can be great.

Parametric Contract Modeling Through Factorial Design

In parametric cost estimating, certain parameters or features of a part are identified as the key cost drivers (KCDs). A cost relationship is established that expresses these parameters or features as a function of cost.23 For example: the three parameters-total production quantity, volume (size), and raw material type-may be used alone to derive a ball-park cost for a sand-cast part. The response from a sand-casting contractor for a ball-park cost estimate may well be based on such an approximation. A more accurate cost, however, would be possible if more parameters were identified and modeled, such as the required number of cores, the parting line tolerance, the tolerance and surface finish requirements, and so on. Clearly, the more parameters that can be identified, the more specific and, therefore, accurate the estimate, provided, of course, that the cost relationship of such parameters is known.

The advantage of parametric cost estimating for this application is that the features of the part, that is, the inputs to the model, are in the product designer's domain. They can be identified manually by the designer with relative ease and offer the potential of automatic identification through feature recognition techniques in a CAD environment.

The parametric contract modeler utilizes contract quotes to establish the cost models of the key cost drivers. Contract quoting is arguably the most reliable method of cost estimating as it is directly linked to the stochastic fluctuations associated with the manufacturing contract business. These variations occur in both the geographic and time domains and are typically linked to nondeterministic parameters, such as the level of local and global competition, raw material availability and costs, labor availability and rates, stock market and political shifts, and so on. For outsourced parts and processes, contract quoting provides a detailed cost breakdown with little to no percentage error. The problem, however, with contract quoting, particularly at the early conceptual design stages, is the time involved. Time is taken to put the quote packages together (with full detail drawings), there is a time delay in processing and returning, and there is time for comparative evaluations when alternative designs and associated processing approaches are being considered. In this approach, the time problem is overcome by using a contract quote derived parametric model.

A factorial design methodology has been developed to model the results of a planned set of quotes whereby a "datum part" is varied to reflect the full range of key cost drivers. Figure I shows the main stages of the methodology, which starts with a detailed study of the manufacturing process to be modeled and the preliminary identification of the process cost drivers. A full factorial design experiment is then carried out using off-the-shelf cost estimating software or mechanistic models to help identify the KCDs. Once this has been done, a fractional factorial design experiment is formulated that varies the KCDs of the datum part to match expected main effects and interaction effects. Drawings and quote packages are then prepared and sent out to contractors. The resulting quotes are statistically analyzed and error estimates are made. The iterative loop (that is, reversing the arrow in Figure 1) allows for refinements of the KCDs and remodeling in the presence of unacceptable model accuracy.

The fractional factorial design approach is necessary to reduce the size of the quote packages to a practical level. Some assumptions are made regarding high-order interactions and confounding. These assumptions are then tested and verified.

Experimental Results

The processes chosen for these experiments were injection molding, sheetmetal stamping, and turning. These were chosen because they represent three very different fundamental process types. Three complete models were developed for the injection molding process utilizing a comprehensive set of quotes from two local injection molders and a commercial cost estimating package. For the sheetmetal stamping and turning processes, only simulated contract quotes were developed using the cost estimating package. In this way, an evaluation could be made of the methodology and any difficulties in defining and evaluating parameters for these processes without incurring the cost of the "real" contract quoting process. The procedure and results of modeling the injection molding process will now be described in some detail to demonstrate the methodology.

The first stage in the model development process was to carry out the rough-cut experiments, determine the key cost drivers, and determine the range of these parameters (high and low values). Fifteen key cost drivers were initially identified. Full factorial rough-cut test runs utilizing the commercial cost estimating package indicated that model complexity could be minimized by considering material cost separately as a simple function of volume and that other variable effects and interactions could be scaled to suit without significantly compromising model accuracy. Also, four of the initial KCDs were found not to have a significant effect on cost and were removed from the model. The main interaction effects were identified, and from this a 2 11-4 fractional factorial experiment was designed for the contractor quoting stage. The final KCDs are listed in Table 1 with variable definitions identified by high and low values. X sup1 characterizes the complexity of the parting line, X sup2 and X sup3 are the number of holes and surfaces, respectively, X sup4 and X sup5 are the need for moving cores (outer and inner), X sup6 is any screw forms (rotating mandrels), X sup7 is the tolerance or degree of precision, X sup8 is the need for additional additives, such as color, X sup9 is the texturing of the mold surface, XA is the degree of surface finish, and XB is the type of raw material (high and low levels are scaled according to the volumetric cost of the respective materials).

A 2 11-4 notation signifies that four variables have been added to a standard 2 sup7 full-factorial design involving seven two-level variables. The resulting design therefore analyzes 11 variables with only 2 sup7 , or 128, contract quotes. A full-factorial design of all 11 variables would have required 211 or 2048 quotes.

While fractional factorial designs reduce the number of tests required for an experiment, they do not give clear estimates of all main effects and interactions. Some of the estimates generated from these designs will actually be estimates of groups of effects. Effects included in these groups are said to be confounded. Adding more variables to a design increases the number of confounded effects.24

The chosen fractional factorial design added the four variables, X sup8 = X supI X sup2 X sup3 X sup7 , X sup9 = X sup2 X sup3 X sup4 X sup5 , XA = X sup1 X sup2 X sup3 X sup4 X sup6 , and XB = X sup4 X sup5 X sup6 X sup7 , to the standard 2 sup7 full factorial design. This particular experimental design does not confound any groups of twofactor interactions, so clear estimates of all main effects and interaction effects may be generated from this experiment, assuming three-factor and higher interactions to be negligible. The initial rough-cut run indicated this to be the case.

(Table Omitted)

(Table Omitted)

Captioned as: Table

Mold part drawings were constructed for the tests, and the 128 drawings were sent to three independent contractors for quoting. The contractors were asked to provide tooling cost and piece-part cost estimates for each test. It was decided that production quantity and tooling issues would be best served by asking

the contractors to supply independent costs for each piecepart excluding tooling, and separate total tooling-up costs. The product development team typically has two basic cost objectives or budget constraints to consider:

1. The investment cost or the direct up-front cost required to take the product to market, the cash flow constraint, or the cash risk. This is the cost to tool up (that is, the amount the mold maker charges to design and build the mold set) and does not include capital equipment investment, machine depreciation, and so on. These nonrecurring costs are referred to as the "tooling cost."

2. The manufacturing cost, referred to as the "piece-part cost" of each product unit, that is, all recurring costs created during production and costs per unit, once in production, excluding tooling costs.

By providing cost information in this two-part form, with separate recurring and nonrecurring costs, simplicity was maintained while retaining the necessary user flexibility. For example, the user may initially wish to simply ignore tooling costs in the analysis; alternatively, tooling costs may be amortized over production volume, or a simple time-based payback analysis may be used. The results may be directly interpreted so that investment risks versus sales predictions and profit margins may be considered.

One of the contractors was unable to complete the task; however, two full contractor quote sets were received (referred to here as companies A and B) and one cost estimating software set was derived. Main effect and interaction effect estimates were then calculated for each of the three sources of cost data. The main effect estimates and confounded groups of interaction effect estimates were then tested using the analysis of variance (ANOVA) technique.24 ANOVA is a method of decomposing the total variation of data into sources of variation. An effect estimate or interaction estimate is considered significant if it contributes a large amount of variation to the experimental results. In this technique for unreplicated experiments, effect estimates are converted first to "sum of squares" estimates by the equation: SS (Ej) = m Ei sup2 / 4, where Ei is an effect estimate, SS (Ei) is the sum of squares of the effect estimate, and m is the number of trials in the experiment.

Mean squares of the estimates are then calculated by dividing the sum of squares by the degrees of freedom associated with the effect estimate. Mean square values can then be compared to the mean square of the error estimate to determine which effects are significant.

Finally, effect estimates can be compared to the pooled error estimate using an F test.25 The F test is a ratio of sample variances. The ratio of the mean square of the effect estimate to the mean square of the error estimate gives an indication of the significance of the effect estimate. If the F-ratio of an effect estimate exceeds a critical value, then the effect can be considered unequal to the insignificant error variance at some confidence level. The critical value of the F distribution is dependent on the degrees of freedom of the effect and error estimates and on the desired confidence level of the analysis.

A 95% confidence level was chosen for this analysis. These experiments generated 61 estimates of the experimental error, so the F-ratios of the effect estimates were compared to a critical value of F supl , sup6 , supl ,.95 = 4.0. F-ratios that exceed this critical value of 4.0 can be said with a 95% confidence level to contribute a significant source of variation to the experimental results.

The mathematical models based on the cost estimating package quotes, CE, were computed to be:

The mathematical model predictions of the tests were generated and used to calculate model residuals. Example histograms of the residuals are shown for Company A in Figures 2a and 2b.

The piece-part model residuals do not appear to follow a very "normal" distribution; however, the mean

of the residuals is very close to zero, -$.0014, with one standard deviation of $0.01 1. These results indicate that the piece-part cost model accurately represents the experimental data. The tooling residuals are approximately normally distributed with a mean of-$19.7 and one standard deviation of $800. These results are acceptable considering the size of the tooling cost estimates.

(Graph Omitted)

Captioned as: Figure 2b

A good visual example of the closeness of fit can be seen in the diagrams in Figures 3a and 3b. Three parts are shown of the same raw material (HDPE) and same volume of material but of varying complexity. There is close agreement between the actual quote from contractor A (A quote) and the cost estimates derived from the new model (A model). The same is true for the quotes from contractor B and the estimates derived from these.

Figures 3a and 3b also show the differences between three contract quote sources-the two contract molders and the cost estimating package-in particular the differences between the cost estimating package estimates and the two contractors. These demonstrate the difficulties of using currently available cost estimating packages to estimate contract work. It is generally not possible to obtain the necessary contractor information such as labor rates, equipment performance, and equipment cost data. Hence, default values must be used as inputs to the estimator, which can lead to estimates being off by a considerable amount.

There are also some significant differences between the two contractor quotes. These are real differences, and design decisions should be made with full awareness of the free-market variance associated with subcontract manufacture. Contract molders have different machines, different local constraints (such as taxes, labor rates, and so on), different capabilities, and different quoting methods. In future work, there are plans to generate regional and global models and provide the associated variances to the user, improving the validity of costrelated design decisions at the earliest possible stages of the product development process. This cost variance information may also be useful for outsourcing decisions later in the process. Contract Modeler User Interface

The design of any product or tool must be driven by the needs of the customer or user. Cost models on their own have limited value and must be supported with an adequate user interface. This user interface should extract the manufacturing cost information from the models and present it to the user efficiently and effectively. Designers should be able to rapidly evaluate absolute and comparative manufacturing costs as the design emerges.

Analyzing the requirement for the user interface in the DFM environment indicates that this activity should:

not interrupt or interfere with the creative nature of the design process

be quick, easy to use, and sufficiently accurate

provide absolute cost data so that cost targets and marketability issues may be continuously reviewed

provide comparative cost information to evaluate alternative processes and materials

rapidly evaluate the cost of part consolidation or rationalization decisions

evaluate the likely extra cost of add-on features or options

provide a means to better iterate toward an optimum economic design

Working in collaboration with the department's human factors research group, it was decided that two user interfaces should be developed to accommodate the various needs and working environments of engineering/industrial designers: a comprehensive hardcopy handbook of comparative cost charts and a computerized version-an integrated CAD interface. Comparative Cost Charts

The re-expression of data in pictorial form capitalizes on one of the most highly developed human information processing capabilities-the ability to recognize, classify, and remember visual patterns.26 A hardcopy set of graphical cost charts has the potential advantage of speed and flexibility of use in many design and product development environments. In previous research,8 the principal investigator studied, in collaboration with the department's human factors group, a number of methods of utilizing hardcopy charts for graphically presenting comparative cost information.

With the results of this study in mind, some initial work has been done to ergonomically present the cost information extracted from the contract models and to study the designer's ability to rapidly glean and assimilate the information contained therein.

(Graph Omitted)

Captioned as: Figure 3a

(Graph Omitted)

Captioned as: Figure 3b

Figures 4a and 4b show some results from the injection molding contract model (averages of contractors A and B). These charts aim to provide the designer with an immediate visual indication of how the choice of material and use of molded-in features affect cost. Figure 4a shows the unit piece-part or recurring costs, and Figure 4b shows the nonrecurring tooling costs. For lower volume applications, the designer will be particular concerned with tooling cost because this must be amortized over the product life volume. A net shape or near-net shape process with high tooling cost may prove not to be economical. Designers can instantly see how much the tooling cost increases if they resort to complex moldings with moving side cores or screw mandrels. Similarly can be seen the relatively small effect on piece-part cost of this added complexity and the much larger effect of going to a higher grade raw material. The designer can review the function, predicted volumes, and tooling-up budget and make a decision with full knowledge of the cost tradeoffs available. Absolute costs can be estimated directly from the charts by comparing the proposed design with the "datum part" and adding costs for each added feature or part parameter. The datum is chosen as a simple part with all key cost variables at the minimum ("low" on the x-axis). At the other end of the scale ("high"), the various key parameters are at the upper cost end. Interpolation may be used between the low and the high tick marks and scaled off the chart. For a quick approximate estimate, the cost of multiple features can be obtained by simply adding up the incremental cost of each.

Similar cost charts are presented in Figures 5a and Sb showing the same chart presentation method employed for CNC turning. Although for a totally different process, the same layout and concept of one chart for recurring cost and one for nonrecurring costs may be used. For practical ergonomic reasons, a generic layout and presentation approach is important, across the range of manufacturing processes available to the designer. In CNC turning, the main nonrecurring costs are the cost of programming; these costs are the "setup cost" of Figure Sb. Once again the datum part is a simple part of 1040 steel, just under stock diameter, that can be simply finish-turned in a single pass, faced off, and parted off. The cost of more complexity, a better finish, removing more material, and a less machinable material are

shown.

The charts of Figures 6a and b demonstrate how direct process comparisons may be made using a similar chart format. A simple u-shaped end bracket for a small pneumatic cylinder is used to demonstrate how piece-part costs and tooling costs vary compared to a datum "machining from solid" approach. Once again the designer may quickly see the effect that the design decision may have on both costs. Integrated CAD Interface

Because many designers use computerized geometric modeling tools, the ability to access the contract models directly from a CAD system is an obvious requirement. Because the contract models are driven by cost drivers that are a direct function of part parameters or "features," the cost models are integrated with the feature-based parametric solid modeler Pro/Engineer from Parametric Technologies Inc. Pro/Engineer's Pro/Develop provides a library of C language routines enabling both application programs and commercial software to interface with Pro/Engineer. Pro/Develop is being used to create such entities as custom menu options and to access the solid model database to obtain such object information as tolerances, dimensions, volumes, surface area, and so on for parametric cost model calculations.

Figure 7 shows a recent photograph of the ProEngineer screen with the new cost/process menus. The user goes through the set of menus "clicking" on the appropriate choices for the part, such as the method of manufacture, material choice, surface finish, and so on. A window then appears displaying the recurring and nonrecurring cost estimate for the design. When complete, it will then be possible to investigate different product design and processing options with immediate cost feedback to iteratively converge on a best solution. Conclusion

The conscientious design engineer is interested in the existence of any tradeoffs that can be made to help converge on the most cost and quality effective design solutions. A basic requirement for assisting the design of the highest quality products at lowest manufacturing cost is to allow what-if scenarios to help in the selection of optimum processes and materials. Such what-if scenarios can only be performed in a timely manner if models exist that can provide a comprehensive simulation environment. To address this need, a parametric contract modeler is being developed to provide the necessary simulated contract quotes.

The following summarize the contributions of this paper:

1. A factorial design methodology for developing cost models from contract quotes has been developed. The approach, termed the parametric contract modeler, aims to provide ball-park manufacturing cost information to engineering designers in an efficient and timely manner for the wide range of manufacturing processes available today.

(Chart Omitted)

Captioned as: Figure 4a

(Chart Omitted)

Captioned as: Figure 4b

(Chart Omitted)

Captioned as: Figure Sa

(Chart Omitted)

Captioned as: Figure Sb

(Chart Omitted)

Captioned as: Figure 6a

(Chart Omitted)

Captioned as: Figure 6b

2. A cost model of the injection molding process was successfully developed using the methodology. Eleven key cost drivers were determined as the necessary input parameters to the model. The results showed that the approach was able to adequately model the complex process with only 128 contract drawings. In the example quoted, piecepart quote residuals were close to zero, -$.0014, with la of $0.011, and the mean of the tooling residuals was only -$19.7 with la of $800.

3. Comparative cost charts have been designed as a user interface for the parametric contract models. The charts extract the manufacturing cost information from the models and present it to the user efficiently and effectively.

4. An integrated CAD interface has also been proposed as a user interface, and results of initial software development work are described. Because many designers use computerized geometric modeling tools, the ability to access the contract models directly from a CAD system is an obvious requirement. Because the contract models are driven by parametric cost drivers, which are a direct function of part parameters or "features," the proposed modeling methodology supports this requirement well. Designers are able to rapidly evaluate absolute and comparative manufacturing costs as the design emerges.

Acknowledgments

The authors wish to gratefully acknowledge the support of General Motors Corp., the General Electric Foundation, the University of Illinois at UrbanaChampaign Research Board, and the Manufacturing Research Center at the University of Illinois.

(Photograph Omitted)

Captioned as: Figure 7

Reference:

References

Reference:

1. J.V Michaels and W.P. Wood, Design to Cost (New York: John Wiley & Sons, 1989).

2. G. Pahl and W. Beitz, Engineering Design: A Systematic Approach (London: The Design Council, 1988).

3. R. Bangasser and J. Tonini, "Nomography-An Estimating Tool," ASTME Paper No. MM66-144 (Dearborn, MI: American Society of Tool and Manufacturing Engineers, 1966).

4. PF. Gallagher, Project Estimating by Engineering Methods (New York: Hayden Book Cos., 1964).

5. D.S. Clark and T.F. McNeil, Cost Estimating and Contract Pricing (New York: American Elsevier Publishing, 1966).

6. "Estimating with a Computer," American Machinist (Nov. 21, 1966), ppl 15-117.

7. L.W. Keller, "The Use of a Computer in Cost Estimating," ASTME Paper No. MM67-680 (Dearborn, MI: American Society of Tool and Manufacturing Engineers, 1967).

8. M.L. Philpott and R.P Nita, "Comparative Cost Charts: A DFM Tool for Cost Estimation in the Conceptual Design Phase of New Product Development," International Conference on Design for Manufacture and Assembly (Newport, RI, June 15-16, 1992).

9. PF Ostwald, Cost Estimating (Englewood Cliffs, NJ: Prentice-Hall, 1984).

Reference:

10. W. Winchell, Realistic Cost Estimating for Manufacturing, 2nd ed. (Dearborn, MI: Society of Manufacturing Engineers, 1989). II. E.M. Malstrom, ed., Manufacturing Cost Engineering Handbook (New York: Marcel Dekker, 1984).

12. PE Gallagher, Parametric Estimating Jor Executives (New York: Van Nostrand Reinhold, 1982).

13. C. Poli, R. Fernandez, and J. Escudero, "How Part Design Affects Injection-Molding Tool Costs," Machine Design (Nov. 24, 1988). 14. C. Poli and L. Fredette, "Trimming the Cost of Die Castings," Machine Design (Mar. 8, 1990).

15. M. Wozny, J. Turner, J. Dixon, C. Poli, and R. Graves, "A Unified Representation to Support Evaluation of Designs for Manufacturability: Phase I," 1991 NSF Design and Manufacturing Grantees Conference (Austin, TX, Jan. 9-11, 1991).

16. M. Wozny et al., "A Unified Representation to Support Evaluation of

Reference:

Designs for Manufacturability: Phase II," 1992 NSF Design and Manufacturing Grantees Conference (Atlanta, GA, Jan. 8-10, 1992). 17. M. Wozny et al., "A Unified Representation to Support Evaluation of Designs for Manufacturability: Phase III," 1993 NSF Design and Manufacturing Grantees Conference (Charlotte, NC, Jan. 6-8, 1993). 18. G. Boothroyd and P Dewhurst, "DFMA Toolkit: Cost Estimating Software" (Wakefield, RI: BDI, 1991).

19. "Variant Process Planning and Estimation System" (Big Rapids, MI: MiCapp Inc., 1991).

20. "Cost Estimating Software" (Milwaukee: Micro Estimating Systems Inc., 1993).

21. P Dewhurst and G. Boothroyd, "Early Cost Estimating in Product Design," Journal of Manufacturing Systems (v7, n3, 1988), ppl 83-191. 22. R.C. McIlhenny, T.R. Sethumadhava, K.S. Lee, and L.K. Keys, "An Integrated System Approach to Injection Molding to Facilitate Early Cost Estimation," Design for Manufacturability (ASME) (DE-Vol. 52, 1993), pp 105-109.

23. J.M. Dascbach and H. Apgar, "Design Analysis Through Techniques of Parametric Estimation," Engineering Cost and Production Economics (vl4, 1988), pp87-93.

24. R.E. De Vor, T. Chang, and J.W Sutherland, Statistical Quality Design and Control (New York: Macmillan, 1992).

25. G.E.P Box, W.G. Hunter, and J.S. Hunter, and J.S. Hunter, Statistics for Experimenters (New York: John Wiley & Sons, 1978).

26. S. Lewandowsky and I. Spence, "The Perception of Statistical Graphs," Sociological Methods and Research (1990), pp 12-18.

Author Affiliation:

Authors' Biographies

Author Affiliation:

Mike L. Philpott is an associate professor of mechanical and industrial engineering at the University of Illinois at Urbana-Champaign. He received his Ist Degree and PhD from Cranfield University (UK). He is a registered professional engineer in Europe and was formerly Director of Integration Technology at Cranfield Institute of Technology. His research focus is on computer-integrated design and manufacture. He has more than 45 technical publications in this area and has a number of ongoing funded research projects in design for manufacture, rapid prototyping, mold and die manufacture, and complex surface metrology.

Chad Warrington is a systems engineer at Caterpillar Inc. (Peoria, IL). He received his BSME from Bradley University and MS from the University of Illinois at Urbana-Champaign. He is currently working in the area of design for manufacture utilizing feature-based design, geometric modeling, and knowledge-based approaches to providing process cost and capability data to design engineers.

Eric Branstad is a research assistant in the Mechanical and Industrial Engineering Department at the University of Illinois at Urbana-Champaign. He received his BSME from Northwestern University and his MS from the University of Illinois at Urbana-Champaign, where he is currently completing his doctoral studies. He is working with a number of industrial organizations to study manufacturing cost and process capability information flow during the product realization process.

Author Affiliation:

Ricardo David is a development engineer at the Ford Motor Co. He received his BSME and MS from the University of Illinois at UrbanaChampaign. His master's degree research was on the development of cost models for the range of sheetmetal fabrication processes commonly available. He is currently working in the area of DFMA at Ford and on new product designs utilizing these methodologies.

Rich P Nita is a project engineer at Motorola (Schaumburg, IL). He received his BSME from Southern Illinois University and his MS from the Mechanical and Industrial Engineering Department at the University of Illinois at Urbana-Champaign. His master's research studied charting methodologies for presenting manufacturing cost information to designers. He is currently a member of new product development teams at Motorola and also instructs at Motorola University on DFMA.

Copyright © Society of Manufacturing Engineers 1996

ABI/INFORM®
© 2007 ProQuest Information and Learning. All rights reserved.
Dialog® File Number 15 Accession Number 1296041

POWERED BY Dialog LOGOFF

Search results: **0** titles

Search Report

Database Name	**Database Number**
BUSINESS & INDUS	9
GLOBAL REPORTER	20
KR/T BUS NEWS	608
NEW PRODUCT ANNMNT	621
MCGRAW-HILL PUBS	624
SAN JOSE MERCURY	634
NEWSLETTER DB	636
BUSINESS WIRE	610
BUSINESS WIRE	810
PR NEWSWIRE	613
PR NEWSWIRE	813
FT INFORMATION LTD	476

Set	**Description**
S1	(((estimating OR calculating)(1N)(1N)(cost OR fee OR charge)) AND ((manufacture(1N)(1w0(1N) (material OR component)))
S2	PY=((1970:2000))
S3	S1 and S2
S4	S3
S5	RD
S6	SORT /ALL/pd,a

Help Tips for 'Zero Records' - How To Get More Records

- Don't over-specify: use only the search options you really need -- leave the others blank.
- Exclude "implied concepts": leave out words like 'research' or 'effects.'
- Use more wildcards to search different word endings: use COMPUTER? in place of COMPUTER.
- Check the format of your entry. Follow the Search Tips examples shown on the search page.
- Check for misspelled words.
- Check that you are using parentheses correctly when you combine words with AND, OR, NOT.

For more tips on searching, see the Help page.

POWERED BY Dialog LOGOFF

Search results: **1707** titles

select all none Titles on this page: Display Checked Display All

Search Report

Database Name	**Database Number**
INSPEC 1898+	2
NTIS	6
EI COMPENDEX PLUS	8
SCISEARCH 1990+	34
SCISEARCH 74-89	434
DISSERTATION ABS	35
INSIDE CONFERENCES	65
APPLIED SCI & TECH	99
TECTRENDS	256
JAPIO - PAJ	347
GLOBALBASE	583

Set	**Description**
S1	((estimating OR calculating) AND ((cost OR fee OR charge) AND (material OR component)))
S2	PY=((1970:2000))
S3	S1 and S2
S4	S3
S5	RD

- ☐ 1 **Independent component analysis through direct estimation of the mutual information** - 2000 - INSPEC
- ☐ 2 **Independent component analysis approach to resolve the multisource limitation of the reticle-based optical trackers** - 2000 - INSPEC
- ☐ 3 **10*10 cm/sup 2/ screen printed back contact cell with a selective emitter** - 2000 - INSPEC
- ☐ 4 **Neural-network-enhanced small low-cost low-power sensor for atmospheric gases** - 2000 - INSPEC
- ☐ 5 **Calculation of average energy of particles of plasma of an abnormal glow discharge in an atmosphere of noble gas, which are bombarding a surface of the cathode** - Aug. 2000 - INSPEC
- ☐ 6 **Design of speech recognition engine** - 2000 - INSPEC
- ☐ 7 **A BLDCM drive with trapezoidal back EMF using four-switch three phase inverter** - 2000 - INSPEC

- ☐ **8** **Characteristic of space charge distribution under DC stress in glass materials** - 2000 - INSPEC
- ☐ **9** **Unsupervised ICA neural networks applied to reticle optical trackers** - 2000 - INSPEC
- ☐ **10** **Mass spectrometer calibration of Cosmic Dust Analyzer** - 2000 - INSPEC
- ☐ **11** **Microfabrication of polymers using ion micro beam** - July 1999 - INSPEC
- ☐ **12** **A new finite element method of the eddy current problem in thin conducting plates** - Jan. 2000 - INSPEC
- ☐ **13** **An integrated cost model for software reuse** - 2000 - INSPEC
- ☐ **14** **Numerical solution of coupled boundary value problem of heat transfer equation for multi-layer PV cells. II. Nonsteady state conditions** - 1998 - INSPEC
- ☐ **15** **Research on ventilation structure of 3-phase medium size high voltage asynchronous motor** - 2000 - INSPEC
- ☐ **16** **Estimating reflection parameters from a single color image** - Sept.-Oct. 2000 - INSPEC
- ☐ **17** **Nonunidirectional energy exchange at the two-wave interaction in cubic photorefractive crystals under a square-wave electric field** - 1999 - INSPEC
- ☐ **18** **Subsurface permittivity estimation from ground-penetrating radar measurements** - 2000 - INSPEC
- ☐ **19** **Manufacturing cost modeling for product design** - April 2000 - INSPEC
- ☐ **20** **Plasma position measurements in a tokamak with an iron core transformer** - July 2000 - INSPEC

Display more titles: **1-20** 21-40 41-60 61-80 81-100 [Next 100]

select all none Titles on this page: Display Checked Display All

To display full records, click a title or use the checkboxes and display buttons